

NEUTRON SOURCE CALIBRATIONS AT NBS FOR CALIBRATION CHECKS OF NEUTRON RADIATION INSTRUMENTS

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The manganous sulfate bath method of neutron source calibrations at the NBS is described together with the corrections applied for neutron capture in the source itself, capture by competing nuclei of either fast or thermal neutrons, and thermal neutron leakage. The advantage of commercially available Am-Be (α, n) neutron sources as a calibration check for radiation instruments in the MeV range is stressed.

(Neutron source; calibration; manganous sulfate; radiation instruments)

Introduction

This paper describes the manganous sulfate bath method used at the NBS to calibrate the emission rate of neutron sources. For a more thorough review of and references to the measurement of neutron emission rates and neutron spectra see reference (1) by Caswell.

Neutron sources which are used for the calibration of neutron radiation instruments are selected on the basis of their size, stability, predictable and long half life, energy spectrum, and emission rate. The emission rate is used to calculate the strength of the neutron field at the position of the neutron radiation instrument. Neutrons emitted from these sources are not of uniform energy and therefore require fluence-dose conversion factors to give a true calibration of a neutron dosimeter. It is not the purpose of this paper to describe such a complicated procedure for any given instrument, but to recommend that, once such a relationship is established, the operation is most easily checked over long periods of time by an Am-Be(α, n) neutron source.

Calibration of Neutron Emission Rates

At the NBS the manganous sulfate bath method² is used to compare the neutron emission rate of an unknown source to the standard radium-beryllium, photo-neutron source, NBS-I. The principle of the method is shown in Figure 1. The source is placed in a thin-walled, air-filled, teflon beaker at the center of a 125 cm dia-

meter sphere of manganous sulfate solution. Due to the large size of the bath very few neutrons escape. The remainder are captured by any of the following processes: (1) fast capture in the fluorine of the beaker, (2) fast capture in ^{16}O or ^{32}S , (3) slow neutron capture in ^{55}Mn or hydrogen, or (4) slow neutron capture in the beaker or the source itself. The slow neutron capture in ^{55}Mn produces ^{56}Mn , which decays to ^{56}Fe with a half life of 154 minutes. It is the gamma activity of the ^{56}Fe which is measured at the sodium iodide crystal. The induced activity of the bath is measured for the unknown source and for the standard source, NBS-I. The ratio of the source emission rates is determined from the ratio of the two count rates after corrections have been applied for escape and capture in other nuclei.

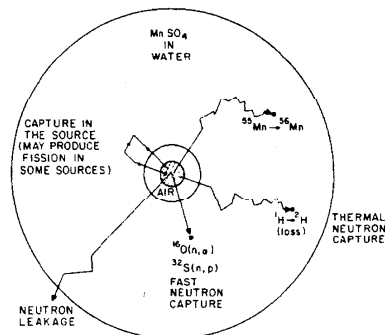


Fig. 1 Manganous Sulfate Bath Source Calibration (Schematic)

A circulating manganous-sulfate bath system, as shown in Figure 2, is used at the NBS. The circulating pump thoroughly mixes the bath solution by maintaining a flow rate of about 70 liters per minute through a dispersive nozzle. About 6 liters of solution per minute flow to a remotely located gamma-ray counting system, where counting can be continued and statistics accumulated as long as desired. The Sodium-Iodide crystal, located at the center of the Marinelli beaker, is used for neutron sources with emission rates between 10^5 to 10^8 neutrons per second. The second crystal, located above the Marinelli beaker, views a small fraction of the activated solution through the lead shield and is used for neutron sources with an emission rate between 10^8 and 10^{10} per second. The second crystal is needed for more intense neutron sources, because the main crystal counting system would be paralyzed by the resulting manganese activity. The relative efficiency of the two counting systems is measured by using an intermediate neutron source with an emission rate of about 10^8 per second, which can be counted simultaneously by both systems.

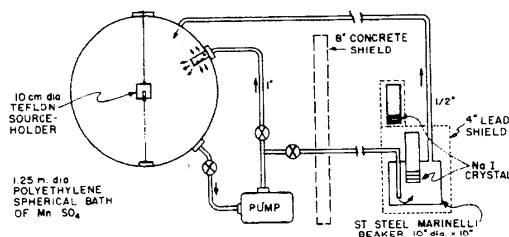


Fig. 2 Circulating Manganous Sulfate Bath and Shielded Gamma-Ray Detector

The uncertainties in a calibration are listed in Table I. The most recent absolute calibration of NBS-I by Noyce, et al.³ was quoted with an error of $\pm 1\%$. Escape from the 1.25 meter diameter bath is quite small even for the higher energy (α, n) neutron sources and essentially non-existent for low energy (γ, n) neutron sources. The error in the correction depends upon the size of the correction. A correction is applied for capture in the source itself. In the

Table I

Uncertainties in the Calibration of Neutron Sources

Systematic Errors	(α, n)	(γ, n)
Emission Rate of NBS-I	1%	1%
Escape	0.2%	0%
Absorption in Source	0.1-0.3%	0.1%
Fast Neutron Loss to Reactions	1%	0%
Random Error		
Counting of Activated Bath	0.2%	0.2%
Total Error	1.6-1.7%	1.3%

case of sources containing fissionable material, such as plutonium, neutron multiplication by thermal capture in the fissionable material may partially cancel or be larger than losses due to capture in the source encapsulation. This correction is minimized by locating the source in an air cavity with thin teflon walls to reduce the thermal neutron flux. The correction is calculated⁴ for each individual source and its accuracy again depends on the size of the correction. The least well understood correction, which is very important for (α, n) sources because they have many neutrons with energies above 3 or 4 MeV, is the loss of fast neutrons due to reactions such as $^{16}\text{O}(n, \alpha)$ and $^{32}\text{S}(n, p)$. Calculations of this correction by Murphey⁵ are used for our calibrations, but, because these disagree with some experimental measurements¹, there still appears to be an uncertainty of about 1% in the correction for (α, n) sources.

The total errors listed in Table I result from the linear addition of the quadratic sum of random errors and quadratic sum of systematic errors.

$^{226}\text{Ra}-\text{Be}(\alpha, n)$ sources increase in neutron source strength due to the growth of ^{210}Po . ^{210}Po decays with a half life of 138.38 days and is formed by the alpha decay of ^{210}Pb in the radium decay chain with a

half life of 22.3 years. The relative source strength as a function of time in years from the date of separation of ^{226}Ra is given by the following relationship⁶,

$$F(t) = 1 + .143(1.01437 - 1.03166e^{-t/31.138} + .01728e^{-t/.5466}). \quad (1)$$

$^{239}\text{Pu-Be}(\alpha, n)$ sources increase in neutron source strength due to the growth of ^{241}Am . ^{241}Am is formed by the beta decay of ^{241}Pu with a half life of 14.89 years. If the atom percent of ^{241}Pu in relation to the other neutron emitting Plutonium isotopes are known at the time of manufacture the growth of a Pu-Be (α, n) source can be calculated by a rather complicated formula, which will not be included here, but may be found in an article by Caswell⁷.

Instrument Calibration Checks with Commercially Available Sources

The sources commonly used for instrument checks are $^{241}\text{Am-Be}(\alpha, n)$, $^{226}\text{Ra-Be}(\alpha, n)$, and $^{239}\text{Pu-Be}(\alpha, n)$. Their average neutron energies are approximately 3.9 MeV, 2.8 MeV, and 3.4 MeV respectively. Only the Americium sources have a single well known half life (433 yr), which is predictable over long periods of time. If great care is taken in determining isotopic composition of the source material before manufacture, an accurate effective half life can be determined for the other two sources. However, this information is not always available and is often lost or forgotten.

Another popularly used neutron source with emission rates up to 10^{10} per second is ^{252}Cf spontaneous fission. Its spectrum has been well studied⁸ and it can be manufactured to approximate, very closely, a point source. However, it does have an inconveniently short half life of about 2.64 years and contains ^{250}Cf and ^{254}Cf , which further complicates the determination of the effective half life.

References

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